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Evaluation of thermal performance in cold storage applications using EG-water based nano-composite PCMs

Yaoting Huang, Xiaohui She, Chuan Li, Yongliang Li, Yulong Ding*

Birmingham Centre for Energy Storage (BCES) & School of Chemical Engineering, University of Birmingham, Birmingham B15 2TT, UK

Abstract

In this paper, EG of different concentration was added in water to form PCM with different freezing point. Then, 0.0625%, 0.125%, 0.25% and 0.5% MCNT was dispersed in to each EG-water basefluids respectively. The latent heat are 160.0, 141.0, 102.0 and 85.5 J/g and melting point are -12.2, -15.7, -22.1 and -25.4 ^{o}C for 15%~30% EG-water basefluids. We found that adding MCNT has very little influence on the latent heat and melting point because the total amount of MCNT is very small. Also, we noticed that thermal conductivity will increase with increasing amount of MCNT concentration in EG-water basefluids. An interesting observation is that the enhancement of thermal conductivity was much greater in solid state samples than liquid state samples. For example, in 0.5% MCNT sample, the enhancement of thermal conductivity in solid state was observed over twice higher than that in liquid state.

Keywords: nano-suspension, MCNT, rheologycial behavior, viscosity, phase change materials, cold storage.

* Corresponding author. Tel.: +44-121-5279.
E-mail address: y.ding@bham.ac.uk.

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1. Introduction

Cold storage technology includes storing cold thermal energy to a medium and then releasing it from that medium for later usage. Such a technology has wide applications, like air conditioning[1], refrigerated vehicles[2], cryogenic power generation[3] and so on. Li et al.[4] has provided a detailed review for cold storage mateirals for sub-zero applications. In the review, Ethylene glycol (EG) and water mixture is considered an ideal heat transfer fluid for cold storage applications due to its varying freezing point below zero. Suganthi et al.[5] prepared ZnO-EG-water nanofluids, they found that sample containing 4 % nanoparticles showed thermal conductivity enhancement of 33.4 %. Sundar et al. [6] investigated the thermal conductivity and viscosity of Al_2O_3-EG-water nanofluids. They used different ratio of EG to water ranging from 20/80 to 60/40. They found that among all the nanofluids, maximum thermal conductivity was observed in 20/80 EG-water with 1.5% particle concentration. Similarly, maximum viscosity was observed in 60/40 EG-water with 1.5 % particle concentration. Bhanvase et al.[7] demonstrated that by adding TiO_2 nanoparticles in 40/60 EG-water mixture, the heat transfer coefficient can be enhanced by 105 %.

However, the idea of using the EG-water based nanofluid as a phase change material still has not been attracted much attention and the potential could be unfavorably hindered due to the lack of experimental data among recent researchers' works. Therefore, there is a strong need for more experimental work and scientific analysis on the thermal properties of EG-water nanofluid relating particularly with the cold energy storage process. To evaluate the thermal performance of EG-water based PCM and fill the research gap, we measured a series of cold energy storage related properties including latent heat, melting point, thermal conductivity.

2. Experimental methods

2.1. Materials and preparation

In this work, MCNT with >98% carbon basis, 10 nm outer diameter, 4.5 nm inner diameter and 3~6 μm length (CAS 308068-56-6) and ethylene glycol (EG) with purity of 99.5% (CAS 107-21-1) were purchased from Sigma Aldrich. Distilled water was obtained from an lab water still (Calypso water still, Fistreem International Ltd). To maintain the stability of the nano suspension, SDBS (CAS 9000-01-5, Sigma Aldrich) was used as surfactant.

The two-step method for preparing nano suspension is a process by dispersing nanoparticles into base fluids and it was applied in this work[8]. Firstly, Firstly, Firstly, EG and water were mixed at the ratio of 15/85, 20/80, 25/75 and 30/70 respectively to make basefluid with different phase change temperature.. Then, a certain amount of MCNT corresponding to volume fraction and the same amount of SDBS was dispersed into the mixture of EG and water and stirred by a magnetic stirrer for 10 min. After that, the pre-processed nano composites were further treated continuously for 1 h using an ultrasonication probe. The sample preparation procedure is shown in Fig.1. The volume fraction of MCNT were 0.0625%, 0.125%, 0.25% and 0.5% respectively and the mass of added MCNT were calculated correspondingly as following:

$$\varphi = \frac{m_{MCNT}/\rho_{MCNT}}{(m_{MCNT}/\rho_{MCNT})+(m_b/\rho_b)} \tag{1}$$

where φ represents the volume fraction of nano-suspension, m_{MCNT} and m_b are the mass of MCNT and base fluid respectivel, ρ_{MCNT} and ρ_b determine the density of the MCNT and base fluid respectively.

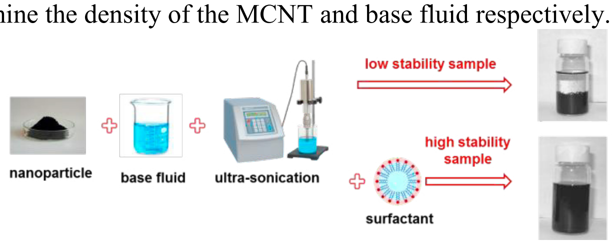

Fig.1. schematic of sample preparation.

2.2. Methodology of characterization

Differential scanning calorimeter (DSC) from Mettler Toledo (DSC 3, Mettler Toledo, Switzerland) was used to find the onset of the melting process and the heat of fusion by integrating the endothermic peak area on the heat flow curve. Thermal conductivity was measure by a transient method called laser flash method, the laser was generated by STARWELD 40, ROFIN, Germany and the laser signal was detected and recorded by LFA 427, Netzsch, Germany. By analysing the laser signal, we could get thermal diffusivity of the sample directly and then thermal conductivity by calculating with input value of specific heat and density.

3. Results and discussion

3.1. Melting point and heat of fusion

3.1.1. Effect of EG concentration

Fig.2 (a)-(d) show the DSC curves of EG-water mixture at various component ratio, which are 15%, 20%, 25% and 30% respectively. One can see that latent heat are 160.0, 141.0, 102.0 and 85.5 J/g, melting point are -12.2, -15.7, -22.1 and -25.4 ^{o}C corresponding to 15-30% EG concentration. It is obvious that both latent heat and melting point decrease with the growing up of the proportion of EG in the total mixture.

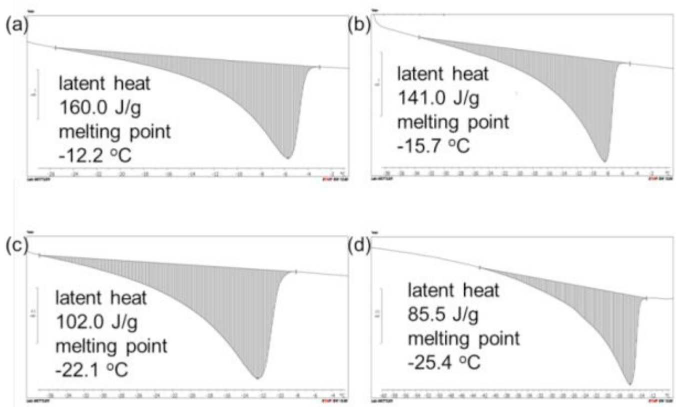

Fig.2. latent heat and melting point of (a)15%, (b)20%, (c)25% and (d)30% EG.

3.1.2. Effect of particle volume fraction

Fig.3 reveals the relationship between the amount of added MCNT and the latent heat and melting point. As expected, the heat of fusion drops linearly with the particle volume fraction, which is in good agreement with the theoretical value. One can find that the in each figure of Fig.3 (a) to (b), melting point keeps almost unchanged at various volume fraction. It seems that the undissolved component of the mixture has very little effect on the phase change temperature.

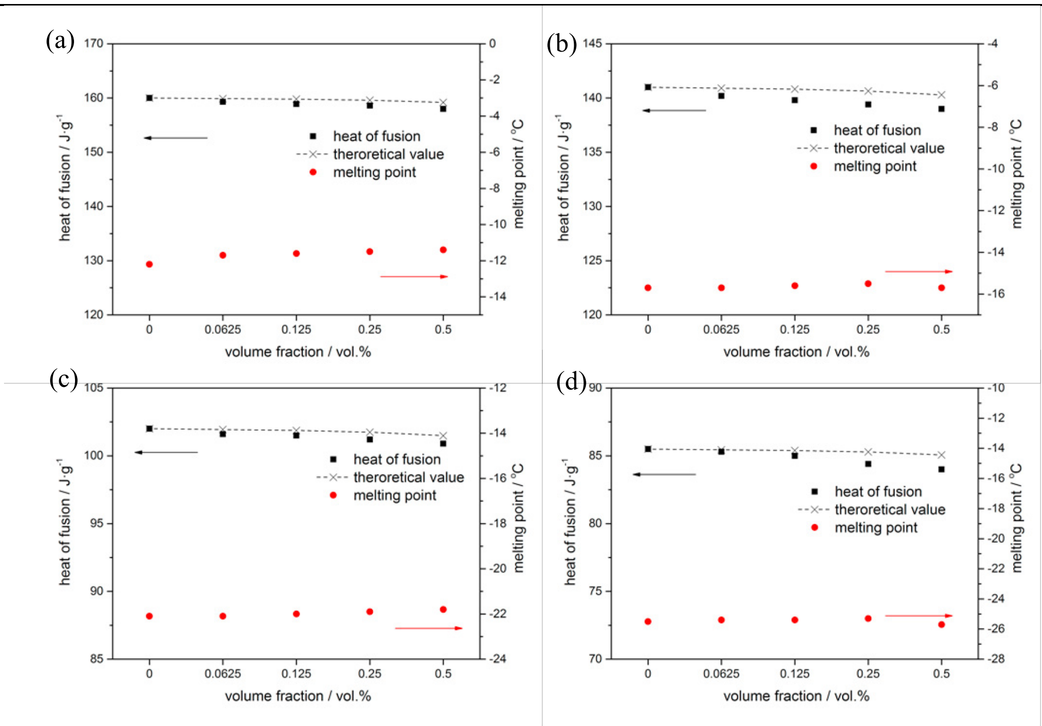

Fig.3. heat of fusion and melting point of (a)15%, (b)20%, (c)25% and (d)30% EG based nanofluid.

3.2 Thermal conductivity

3.2.1. Effect of EG concentration

Two temperature conditions were used to measure the thermal conductivity of EG-water in both liquid and solid phase. When samples are in liquid state, Fig.4 (a) shows that the thermal conductivity drops from 0.590 to 0.488 W/mK linearly with the increasing of the concentration of EG, which could be well predicted by the mixing theory. But Fig.4 (b) exhibits that when EG-water samples are frozen, the thermal conductivity cannot follow the linear rule anymore. For example, when there is no EG in the water, namely, the mixture is pure ice, the thermal conductivity is 2.2 W/mK. And If we further increase the content of EG to 30%, we will surprisingly find that the thermal conductivity drops to nearly half of the original value.

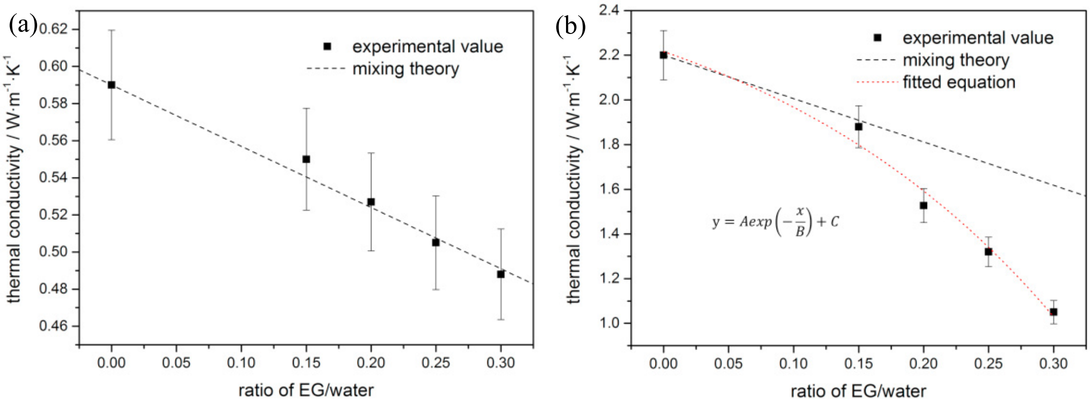

Fig.4. thermal conductivity of EG-water in (a) liquid and (b) solid phase.

3.2.2. Effect of particle concentration

To investigate the thermal conductivity of EG-water based MCNT nano composite PCM during charging and discharging process. We plotted the bar chart of relative thermal conductivity of nanocomposite samples in both liquid and solid state. Fig.5 demonstrates that adding MCNT can enhance then total thermal conductivity of the composite PCM and the more particle is added, the higher enhancement we could obtain. One can see that, the enhancement of thermal conductivity does not vary very much with the property of base fluid.

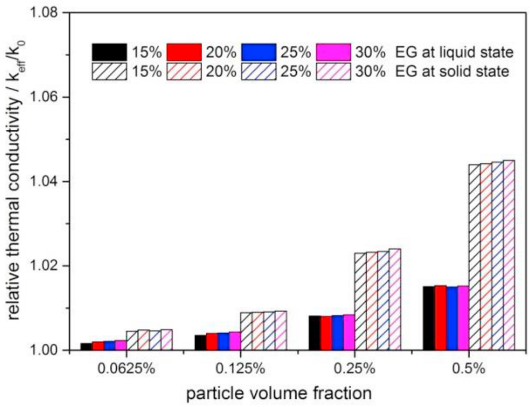

Fig.5 relative thermal conductivity in both liquid and solid state.

Another apparent result is that the enhancement of thermal conductivity in solid state is much higher than that in liquid state. For example, in samples containing 0.5% MCNT, the enhancement are 1.5% and 4.5% respectively in liquid and solid state. It means that by only freezing the sample, the enhancement of thermal conductivity could triple. The similar phenomenon was illustrated by Gao[9]. They proposed a mechanism contributing the different effective thermal conductivity to different particle aggregation structure caused by freezing and melting of PCM. This proposed theory could be a rational explanation of our results.

4. conclusions

In this paper, 15%, 20%, 25% and 30% EG was added in water to form PCM with different freezing point. 0.0625%, 0.125%, 0.25% and 0.5% MCNT was dispersed in to each EG-water basefluids respectively. Effect of EG concentration and MCNT concentration on latent heat, melting ponit and thermal conductivity was studied separately. We found that latent heat, melting point and thermal conductivity will decrease with increasing EG concentration in the mixture. However, the adding of MCNT does not show very significant affect on both latent heat and melting point due to the amount of MCNT is very small. We also noticed that thermal conductivity of solid EG-water basefluid is much lower than the theoretical value by mixting theory. Also, freezed MCNT-EG-water samples shows greater thermal conductivity enhancement than its liquid state. Such a high enhancement could be contributed to the structure of MCNT aggregation.

Acknowledgements

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